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THE CLASSIFICATION OF EUROPEAN GLACIAL DEPOSITS.

WHEN the "Superficial Formations" of Europe began to attract attention, geologists soon discovered that these could be naturally classed under two heads. The lower and therefore the older deposits were characterized especially by their confused and tumultuous appearance, while the overlying younger formations showed a more or less orderly arrangement in layers or beds. The confused accumulations of the lower group were generally believed to be the products of some kind of cataclysmic action—perhaps, as some thought, the Noachian Deluge, or, according to others, mysterious debâcles and waves of translation, caused, it was imagined, by titanic disturbances of the earth's crust. By common consent the tumultuous deposits came to be known as *Diluvium*, while the overlying bedded accumulations were termed *Alluvium*, and were attributed to the action of water under those normal conditions of the surface that now obtain. It is unnecessary to ask why the diluvial explanation of the drift-phenomena ever commended itself to competent observers. Perhaps geologists had not yet quite freed themselves from the influence of their predecessors, whose heroic attempts to cut Gordian knots figure so prominently in the early literature of the science. One thing is certain that the principal advocates of the diluvial doctrine were ignorant of modern glacial action, and, with a few notable exceptions, had only the most cursory acquaintance with the phenomena which they sought to explain. That their diluvial notions should have appeared reasonable to themselves and satisfactory to their disciples, who knew less, need not surprise us. Even in our own day we may see how the same doctrines can appeal to one who has merely a superficial literary acquaintance with the subject. The copious outpourings of Sir H. H. Howorth, if they have neither aided nor retarded the advance of glacial geology, have at least shown what a large field of profitless labor the pseudo-scientific wise men of Gotham have hitherto neglected to cultivate.

Long after the various diluvial hypotheses had been abandoned, and the glacial origin of the so-called *Diluvium* had been recognized, the deposits included under that term continued to be lumped together. Certain accumulations in mountainous countries, it is true, were believed to be moraines of local glaciers, but the "great northern drift" of the European low-grounds was looked upon as iceberg-droppings, and the whole diluvial formation was considered one and indivisible. Even after the dressed rock-surfaces and bowlder-clays of lowland regions had been assigned to the action of glaciers and ice-sheets, geologists continued in the belief that the Diluvium was the product of one protracted period of cold conditions. For a long time the only classification attempted was the subdivision of the drift series into morainic and marine accumulations. No one had as yet suspected the existence of what are now known as interglacial beds. Some of these, it is true, had been examined and described, but their true relation to the glacial deposits had not been recognized. Thus, up to a recent date, geologists—whatever their views might be as to the subglacial or submarine origin of the "drift" as a whole—did not doubt the unity of the Glacial Period. It was in Switzerland that the true meaning of interglacial deposits was first ascertained. Morlot, Heer, and others have put on record the observations which led them to conclude that the Alpine Lands have been subjected to two successive glaciations—the one separated from the other by a prolonged epoch of erosion and accumulation, under climatic conditions somewhat similar to those now existing. Meanwhile, geologists in Britain had discovered that the drift deposits formed a triple series—namely, (*a*) lower bowlder-clay, (*b*) middle sand and gravel, and (*c*) upper bowlder-clay. And some were inclined to consider this grouping as roughly corresponding to the threefold arrangement of the Swiss deposits, and to infer that in the British area there had been two glacial epochs separated by an interval of submergence, when somewhat milder climatic conditions prevailed. In Germany, likewise, an "upper" and a "lower" Diluvium had been recognized long before the true significance of these groups dawned upon geologists. As observations increased it was found that here and there, in Scotland and elsewhere, beds of peat and fossiliferous fresh-water deposits appeared intercalated in bowlder-clay, or separating a lower from an upper bowlder-clay. By those who were of opinion that bowlder-clay is a ground moraine these intercalated beds were looked upon as evidence of glacial oscillations, of no great magnitude. It was supposed that the former glaciers and ice-sheets were subject, like their modern representatives, to temporary movements of advance and retreat. During a time of retreat vegetation spread over the ground vacated by the ice, and when the next forward movement took place the glaciers reoccupied the area invaded by plants, and buried the old soils under fresh accumulations of glacial débris. The upholders of the iceberg origin of the drifts did not attempt to account for the appearance of such intercalated fresh-water beds. It was easier to belittle their importance or to ignore them altogether. The deposits in question have now been encountered, however, in so many formerly glaciated areas that it is no longer possible to pass them by as accidental occurrences that may in time be somehow or other explained away. Their true significance is now the only question in dispute. Do they indicate mere local and temporary movements of glacial retreat and advance, or are they relics of long-continued milder conditions occurring between separate and distinct glacial epochs?

At first sight the former view appears the more reasonable, and to those who have never studied the phenomena accompanying interglacial deposits, it naturally has a special attraction. It is so simple, and so much in accordance with what is actually known of modern glacial action, that those who hold it may be excused for wondering why it is not generally accepted. We are referred to the glaciers of New Zealand which descend into the region of tree-ferns, and to certain glaciers of the Himalaya and Alaska with their tree-covered moraines, and are asked to consider how readily in those regions vegetable débris may become entombed in glacial accumulations. But there is no need to go so far abroad for similar phenomena. Even in the Alps in our day glaciers have advanced and buried trees and vegetable soil under their moraines. Unfortunately, however, none of these cases helps us to account for the interglacial beds of temperate Europe. If the latter never yielded other than Arctic-alpine plants something might be said for the explanation in question. During the climax of the glacial period, when the Scandinavian "inland-ice" invaded the low grounds of middle Europe, those low grounds supported an Arctic-alpine flora. It is obvious, therefore, that when temporary retreats and advances of the ice-front took place, the only relics of plant-life that were likely to be preserved in glacial deposits would be Arctic forms. But although such are not wanting at certain horizons in the glacial series, yet the most conspicuous interglacial beds are charged with the relics of a flora and fauna which could not possibly have flourished in the immediate vicinity of a great ice-sheet. Indeed, the interglacial beds, traced at intervals from Holstein through the heart of Germany to central Russia, contain a flora indicative of more genial conditions than are now met with in the same regions. One may feel quite sure that when the low grounds of middle Europe were clothed with such a flora, and tenanted by elephants and other large herbivora, no great Scandinavian ice-sheet could have existed. There is no reason to doubt, in short, that the snow-fields and glaciers of interglacial Europe were not more prominent than those of the Europe of today. And yet the interglacial deposits referred to rest upon and are covered by glacial and fluvio-glacial accumulations. Here, then, we have to do not with mere local oscillations of an ice-front, but with great climatic changes extending over protracted periods of time.

But this is not all,—the long persistence of interglacial conditions is further shown by the amount of denudation and valley-erosion accomplished during interglacial epochs. The best examples I can cite are those described by Professor Penck and others as characteristic of the Alpine Lands. In the valleys descending to the north three conspicuous gravel-terraces may be noted, rising one above the other. The highest displays an average thickness of about 100 feet—its upper surface being some 250 feet above the level of the present rivers. The second terrace (eighty feet or so in thickness) rests like the former upon solid rock, and its upper surface is 130 feet or thereabout below that of the older terrace. The third and lowest terrace, occurring inside the preceding, rests also upon solid rock, and its upper surface is some 125 feet below that of the second terrace. Each of these terraces is of fluvio-glacial origin, and directly connected with a separate series of glacial moraines. Obviously the tale they tell is one of glacial accumulation and interglacial erosion. After the formation of the highest terrace the glaciers retreated, and fluvio-glacial accumulation ceased. The rivers then slowly dug their way down through the fluvio-glacial gravels (100 feet thick) and, thereafter, proceeded to excavate the solid rock to the depth of another 100 feet at least. Thereafter ensued a return to glacial conditions, and over the newly excavated valley was accumulated another sheet of gravels reaching an average thickness of eighty feet. Once more the glaciers retreated, accumulation ceased, and valley-erosion was resumed, the rivers cutting down through the second series of gravels into the solid rock as before, which they trenched to a depth of sixty or seventy feet. Then a third advance of the glaciers took place and a corresponding series of fluvio-glacial gravels was deposited—the upper surface of which now rises much beyond the reach of the greatest river-floods of today. Similar evidence of interglacial erosion is met with in many other mountain-regions of middle Europe—in the Carpathians, the Riesengebirge, the Black Forest, the Vosges and central France. In the last-named region the evidence shows that during the time that separated two glacial epochs the rivers dug out valleys some 900 feet in depth.

Such are some of the facts which have led many observers to believe in the periodicity of glacial action. There are several other lines of evidence that lead to the same conclusion, but it is needless to discuss these here as I have treated them more or less fully elsewhere. All that I shall attempt at present is to sketch in outline the general succession of glacial and interglacial horizons which can be more or less clearly made out in Europe. To avoid confusion I shall give to each of these horizons a separate name.

I. SCANIAN.

The earliest glacial deposits of northern Europe occur in Skåne—the old division of southern Sweden—hence the provisional name I suggest. These indicate the former existence of a great Baltic glacier which overflowed the southern part of the Scandinavian peninsula from southeast to northwest. No glacial deposits have been recognized on this horizon elsewhere in northern Europe. It is most probable, however, that the Arctic-shell beds of Norfolk known as the Chillesford Clay and Weybourn Crag belong to this stage. To the same horizon I assign the first glacial epoch of which we have evidence in the Alpine Lands. At this stage the glaciers of that region filled all the mountain-valleys and in many cases deployed upon the "Vorländer," where their terminal moraines and associated fluvio-glacial gravels are still conspicuous. To the same epoch ought probably to be referred the ancient Diluvium of the plateaux of central France. According to Penck the snow-line in the Alpine Lands must have been depressed some 4000 feet below its present level.

II. NORFOLKIAN (OR ELEPHAS-MERIDIONALIS STAGE).

This stage is typically represented in northern Europe by the well-known "Forest-bed Series" of Norfolk. During the preceding epoch the North Sea was probably not less extensive than it is today—it even encroached upon what are now the maritime tracts of East Anglia. The "Forest-bed Series" of Norfolk points to the retreat of the North Sea from the southern area of that basin. Britain was at that time joined to the Continent and enjoyed a climate not less temperate than the present. The mammalian fauna included *Elephas meridionalis*, *E. antiquus*, *Hippopotamus*, *Rhinoceros etruscus*, *Machærodus*, etc. In the Alpine Lands the same stage is represented by the lignite-beds of Leffe, etc. (N. Italy), containing *Elephas meridionalis*, *Rhinoceros leptorhinus*, etc., and a flora indicative of more genial conditions than are now experienced in the valleys where those deposits occur. On the same horizon are the interglacial beds of Hötting in the valley of the Inn at Innsbruck—the remarkable flora of which similarly testifies to a warmer climate than the present. The so-called Upper Pliocene deposits of France, such as those of Mt. Perrier and St. Prest, belong most probably to this stage of the Glacial Period.

III. SAXONIAN.

To this horizon belong the accumulations of the epoch of maximum glaciation when the Scandinavian *mer de glace* invaded the low grounds of Saxony and the great glaciers of the Alps piled up the moraines of the "outer zone." The stage is well represented, in nearly all the mountain-ranges and elevated plateaux of the continent, by moraines and fluvio-glacial gravels—while heaps and sheets of rock-rubbish and breccia (pseudo-glacial accumulations) point to the action of severe climatic conditions at lower levels. Flood-loams were doubtless also abundantly distributed over the broad valleys and low-lying tracts of extra-glacial regions. But these cannot always be separated from the similar deposits of later glacial stages which must obviously have been deposited over the same tracts. To the same stage ought to be referred those Pleistocene marine beds of Sicily which are charged with a northern fauna.

The Saxonian thus includes the "lower bowlder-clay" of the British Islands; the "lower diluvium" of Holland, central and southern Germany and central Russia; the ground-moraines and terminal moraines of the "outer zone" (Alpine Lands), and their associated gravels; the older moraines of many mountain tracts in middle and southern Europe; the lower breccias of Gibraltar and much of the "rubble-drift" of other regions.

IV. HELVETIAN (OR ELEPHAS-ANTIQUUS STAGE).

The interglacial deposits of this stage having been first detected in Switzerland suggest the term selected. The Helvetian includes a number of well-known deposits, some being marine, while others are of fresh-water and terrestrial origin. The flora and fauna are indicative of varying climatic conditions. Some of the British beds, for example, have yielded a northern and temperate flora, the mammals including mammoth, woolly rhinoceros and reindeer, while others contain the relics of temperate and southern forms, such as *Elephas antiquus*, *Rhinoceros leptorhinus*, *Hippopotamus*, etc. In like manner, the equivalent beds in middle Europe have yielded northern and temperate floras and faunas — the latter including mammoth, *Elephas antiquus*, Irish deer, horse, etc., while the flora betokens a more genial climate than now obtains but subsequently deteriorating. In central and southern Europe the Helvetian stage is characterized by a temperate flora and fauna -- the latter marked by the presence of *Elephas antiquus*, *Hippopotamus*, *Rhinoceros Merckii*, mammoth, etc.

Amongst the more prominent members of the Helvetian group are the interglacial beds of the British area, as in the maritime tracts of the Moray Firth and the Irish Sea, in Lanarkshire, Ayrshire, Edinburghshire, etc.; the Hessle gravels of East Anglia; the beach-deposits of Sussex; the accumulations of Settle Cave, etc. On the Continent, we have certain marine and fresh-water interglacial beds occurring in the Baltic coast-lands;

the interglacial peat, etc., of Holstein, Rixdorf, Kottbus, Moscow, etc.; the lignites of Switzerland and Bavaria; certain beach-accumulations in northern France; the interglacial deposits of Cantal; and the marine terraces cut in the lower breccias of Gibraltar.

To the same horizon I would assign a considerable proportion of the Pleistocene river-deposits of the Thames, the Seine, the Rhine, etc., as well as many of the cave accumulations of western Europe. But to these and other Pleistocene deposits occurring in extra-glacial regions, reference will be made in the sequel.

V. POLANDIAN.

To this stage belong the glacial and fluvio-glacial accumulations of the minor Scandinavian *mer de glace*, and the corresponding deposits in the mountain tracts of central and southern Europe. The extreme limits reached by the minor ice-sheet have been only approximately ascertained, and cannot at present be represented by a hard-and-fast line. As the ice-sheet extended well into Poland, this has suggested the provisional name given to the stage.

The Polandian includes the "upper bowlder-clay" and associated fluvio-glacial deposits of the British Islands; the "upper diluvium" of central Germany, Poland, west-central Russia, etc.; and the ground moraines and terminal moraines of the "inner zone" (Alps) together with their accompanying gravels. Contemporaneous with these are certain valley moraines in other mountain regions; as also rubble-drifts and alluvial accumulations in extra-glacial tracts.

That the Polandian forms a clearly marked stage is shown not only by the circumstance that it is separated from the Saxonian by the intervening Helvetian, but by the notable fact that the path followed by the minor *mer de glace* did not quite coincide with that pursued by the preceding greater ice-sheet. Thus in southern Scotland the track of the later ice-flow crosses that of the former in some places nearly at right angles, and the same is the case upon the Continent. The maximum ice-sheet, for example, flowed approximately south across Denmark and the southern Baltic area into Holland and north Germany, while the later *mer de glace* had a more westerly trend.

VI. NEUDECKIAN.

The deposits on this horizon are best developed in the coastlands of the southern Baltic. They are partly of marine and partly of fresh-water origin, and are intercalated between the so-called "lower" and "upper" bowlder-clays of that region. The general aspect of the fauna is temperate—certainly not Arctic. The highest level to which the marine beds have been traced is 1.14 meters, at Neudeck near Freistadt in west Prussia. Probably many of the older alluvia overlying the Polandian in regions over which the succeeding Mecklenburgian does not extend ought to be assigned to the Neudeckian stage.

VII. MECKLENBURGIAN.

The most notable deposits belonging to this stage are the ground moraines and terminal moraines of the last great Baltic glacier. These reach their southern limits in Mecklenburg. Contemporaneous accumulations are the bowlder-clays and terminal moraines of the large valley-glaciers and district ice-sheets of the British Islands, and the terminal moraines occurring in the great longitudinal valleys of the Alps (= "first post-glacial stage of glaciation" of Penck and others).

To the same stage are assigned the *Yoldia*-beds of Scandinavia, and the 100-foot terrace of Scotland with its Arctic marine fauna. Here also come most of the Arctic plant-beds of the British Islands, as well as those which underlie the older peat bogs of Denmark, south Sweden, etc.

VIII. LOWER FORESTIAN.

This stage embraces the deposits of the great fresh-water lake of the Baltic area (*Ancylus*-beds); the lower buried forests occurring under the peat-bogs of northwest Europe generally; and the *Littorina*-beds of Scandinavia in part. No deposits on this horizon have yet been recognized in the Alpine Lands. The evidence as to climatic and geographical conditions furnished by the Lower Forestian of northwest Europe is abundant and clear. The wide horizontal and vertical distribution of forest trees betokens not only a more extensive land-surface than the present, but a better climate. The fauna of the *Littorina*-beds also indicates the former existence of more genial conditions in our seas.

IX. LOWER TURBARIAN.

This stage is most characteristically represented by the peat which immediately overlies the lower forest-bed of our turbaries; by the calcareous tufas of Scandinavia, etc.; by the Carse-clays and raised beaches of Scotland, and the Scandinavian *Littorina*-beds in part, and by valley-moraines and corrie-moraines. The invasion by the sea which marked the passing of the Lower Forestian stage was continued into the Lower Turbarian stage. The climate at the same time became more humid and colder—hence the restriction of forest-growth and the increase of snow-fields. In Scotland glaciers here and there came down to the sea and dropped their moraines upon the beach-deposits—the large majority, however, terminated inland, some of these being true valley-glaciers while a larger number were corrie-glaciers. The general distribution of the moraines indicates a snow-line ranging between 2000 and 2600 feet. In Norway the glaciers were correspondingly of more importance—the position of their moraines pointing to a snow-line in South Norway of 2400 feet or thereabout In the Alpine Lands this stage appears to be represented by the terminal moraines of the so-called "second post-glacial stage."

X. UPPER FORESTIAN.

Overlying the Lower Turbarian of northwest Europe we come again and again upon a second buried forest. The flora and fauna of this stage denote temperate and drier conditions; while the distribution of the forest-bed plainly indicates a formerly wider land-surface, but one not apparently so extensive as that of the Lower Forestian. In Scotland the upper forest-bed distinctly overlies the Carse-clays, etc., of the preceding stage.

XI. UPPER TURBARIAN.

The upper forest-bed is in its turn overlaid by peat — a succession seen in the turbaries over a vast region. Followed from the interior to the coast-lands in Scotland this peat is found passing under the lower raised beaches. The Upper Turbarian was therefore marked by a new advance of the sea. No moraines rest upon these later beaches, and this last epoch of submergence cannot therefore be directly connected with any of the glacial deposits of the interior. It is remarkable, however, that in the highest mountain-groups of Scotland we encounter not only the terminal moraines of the Lower Turbarian, but another and later series, the presence of which implies a snow-line at 3500 feet. In mountains which are under that elevation the lower series of moraines alone puts in an appearance. The inference, therefore, is that the higher-level moraines bear the same relation to the peat-bogs and raised beaches of the Upper Turbarian as the lower-level moraines do to the corresponding accumulations of the Lower Turbarian. This stage must doubtless be represented in Norway by similar moraines at high levels — indeed these are well-known to exist, although they have hitherto been looked upon as simply marking pauses in the retreat of the larger ice-flows of an earlier stage. In the eastern Alps no third "post-glacial stage" of moraines has been recognized, but that is because these mountains have not the requisite elevation. It is in the western Alps that traces of such a stage must be sought for, and I venture to predict that they will yet be recognized.

I should like now to add a few remarks on the methods followed in this attempt to classify and interpret the complex accumulations of the glacial period. In working out the geological structure of a district we all know how helpful it is to discover some well-marked datum-line — some horizon, whose position is fixed, and to which constant reference can be made. Having been assured that interglacial epochs broke up the continuity of the Ice Age, it was obviously important to ascertain which of the glacial accumulations represented the epoch of maximum glaciation. Here, fortunately, there was no difficulty. For many years geologists have agreed that the lower bowlder-clay of Britain and the corresponding lower diluvial accumulations of the Continent are the products of the epoch of greatest cold. It was not going beyond the limits of cautious induction to infer that the epoch of maximum glaciation in northern Europe must have been contemporaneous with the same epoch in the Alpine Lands and other mountainous districts on the Continent. Nothing, I should think, can be more probable than that the diluvial accumulations of the most extensive Scandinavian *mer de glace*, which advanced into Saxony, must be on the same horizon as the moraines of the outer zone at the foot of the Alpine Lands. We may consider the Saxonian, then, a well-determined horizon. The next step was to ascertain what relation the deposits of that stage bore to other glacial accumulations. In Britain we have long held that our lower bowlder-clay is the product of the first and greatest glacial epoch, for hitherto no older deposit of the kind has been recognized in these islands. But although that be true for Britain it is not so for Scandinavia. In southern Sweden a still older bowlder-clay exists — the groundmoraine of a former great Baltic ice-sheet, which overflowed Scania from southeast to northwest — a direction at right angles to that followed by the *mer de glace* of maximum glaciation. Again, in the Alpine Lands, as Professor Penck and his coadjutors have shown, the epoch of maximum glaciation was similarly preceded by a yet earlier ice age of very considerable severity — the glaciers descending to the low grounds, but not flowing so far as those of the glacial epoch that followed. Further, it has been ascertained that between the groundmoraines of those two successive epochs there intervene fossiliferous deposits — the plants of which denote a much more genial climate than is now experienced in the valleys of the Alps. Moreover, the amount of contemporaneous valley-erosion demonstrates that this interglacial stage was one of prolonged duration. It was only reasonable to infer that such climatic changes could not have been confined to Scandinavia and the Alps. If interglacial and glacial conditions obtained in those regions it was obvious that our own islands must have been contemporaneously affected. And the evidence of such climatic changes is found, as I think, in the "Weybourn Crag" and "Chillesford Clay" and the overlying "Forest-bed Series" of Norfolk—the former containing a well-marked Arctic marine fauna, while the latter is charged with the relics of a temperate flora, as well as of temperate and southern mammalian forms. To what extent Britain may have been glaciated when the Arctic shell-beds in question were being deposited we can only conjecture—for the later ice-sheet of maximum glaciation made a clean sweep of almost everything. Were it not for the presence of these marine deposits there would be no evidence in Britain to show that the epoch of maximum glaciation was not the earliest of the series. But the existence of a great Baltic glacier, of an Arctic fauna in the North Sea, and of enormous snow-fields and glaciers in the Alps, implies the contemporaneous existence of considerable snow-fields and glaciers in Britain. It may be safely inferred, therefore, that the Saxonian stage, or epoch of maximum glaciation, was preceded by an earlier but less severe glacial epoch (Scanian stage), the genial Norfolkian stage separating the one from the other.

The next succeeding interglacial and glacial horizons have long been recognized. It is generally admitted by European glacialists that the epoch of maximum glaciation was followed by a more or less prolonged interval of genial temperate conditions. In most glaciated regions the Helvetian stage is represented by fossiliferous deposits, which separate the diluvial deposits in which they occur into an upper and a lower series. So well marked is this division in northern Germany, that long before the significance of interglacial deposits dawned upon geologists, an upper and a lower Diluvium had been recognized. The flora and fauna of the Helvetian stage surely indicate conditions not less temperate than the present. Indeed, the plants occurring upon this horizon in middle Europe imply for the interior of the continent a climate even more genial than that which now obtains. Further, the long duration of the Helvetian epoch is shown by the extensive valley-erosion then accomplished. We may conclude that, at the climax of this particular interglacial stage, the snow-fields and glaciers of Europe were of no more importance than they are in our own day.

If this conclusion be well sustained it is obvious that the ice-sheet of the Polandian stage was separate and independent, and not a mere phase of the greater Saxonian *mer de glace*. The latter had for a long time disappeared before the minor ice-sheet came into existence—and the independence of the latter is still further shown by the fact that its path differed in some important respects from that followed by the earlier ice-flow. In Saxonian times the Baltic basin had little influence upon the general direction of the *mer de glace*, while the course of the succeeding Polandian ice-sheet was obviously to a large extent controlled by that great depression. And similar remarkable differences in the directions followed by the two ice-sheets have been detected in Britain.

From the Scanian to the Polandian the succession is easily read, but from this stage onwards the evidence is rather harder to follow. My own investigations in Britain led me long ago to conclude that climatic oscillations had continued to take place after the formation of our upper bowlder-clay. I found, for example, that subsequent to the retreat of the minor *mer de glace*, underneath which that upper till had accumulated, there supervened an epoch of district ice-sheets and valley-glaciers. The evidence showed clearly enough that the upper till had been partly ploughed out and large terminal moraines piled upon its surface by a still later series of ice-flows. But as no interglacial beds have hitherto been detected between the moraines in question and the underlying bowlder-clay I could not be sure that the epoch of large local glaciers had been separated from that of the Polandian stage by any long interval. It seemed possible that the valley-glaciers were merely the degenerate successors of the minor *mer de glace*, which after retreating had again advanced, before they finally vanished. Nevertheless it was obvious that this later advance could not have been a slight temporary movement, but must have endured for a considerable time, so as to allow of much glacial erosion and the heaping-up of immense quantities of morainic rubbish, and the deposition of great terraces of fluvio-glacial gravels. These conditions I found characterized all the mountain areas of the British Isles. It is to this epoch, in fact, that the final grinding-out of our more conspicuous lake-basins must be assigned. The relation borne by the district and valley-moraines to the Arctic shell-beds was also significant. These latter overlie our upper bowlder-clay and are of later age than the Kames and Eskers of our lowlands. They show in short that, after the melting of the minor ice-sheet, submergence of the coast-lands ensued, to the extent of at least 100 feet below their present level. They further show that this submergence was contemporaneous with the existence of the district ice-sheets and valley-glaciers—for the morainic gravels of the latter merge with the deposits of the 100-foot terrace; and here and there moraines are associated with the latter. Not only so, but it is obvious that many of the large glaciers descending to the sea along the west coast of the Scottish Highlands, filled the fiords and prevented the formation there of marine deposits. Thus the 100-foot terrace is well developed upon the open sea coast, but suddenly dies off when the fiords are entered. In the basin of Loch Lomond, again, the glacier ploughed out certain shelly clays so that its groundmoraine is charged with the débris of marine organisms. It is noteworthy in this case that the fauna of the shell-beds thus largely demolished does not indicate Arctic conditions—the species are for the most part living British forms, while the fauna of the undisturbed shelly clays of the 100-foot beach is decidedly northern and Arctic.

From the evidences thus baldly stated the following conclusions seemed probable:

1. The retreat of the minor ice-sheet was followed by submergence to 100 or 150 feet, and the sea eventually became ten-

anted by a fauna not essentially differing from that of the present, but the climate may have been somewhat colder.

2. Recrudescence of glacial conditions supervened, and great valley-glaciers descended from the mountains, filling up the fiords, and ploughing out preëxisting marine deposits. The climate at that time was Arctic—as shown by the character of the fauna in the undisturbed shelly-clays.

It seemed to me quite clear, then, that the 100-foot beach and the contemporaneous morainic accumulations indicated a distinct stage of the Glacial Period. But it was not quite so evident that this stage had been separated from that of the minor *mer de glace* by a well marked interglacial epoch. It became necessary, therefore, to consider the glacial succession on the Continent for the purpose of ascertaining what light that could throw on the problem suggested by the British deposits. The geologists of Scandinavia, Finland and north Germany had discovered the existence of certain great terminal moraines, which, as De Geer showed, must have been accumulated by a great Baltic glacier. These moraines were considered generally to mark a pause in the retreat of the minor *mer de glace*—that, namely, of the Polandian stage—and it struck me as not improbable that in them I had the equivalents of the similar accumulations of our islands. Outside of the great moraines there could be no doubt about the occurrence of two bowlder-clays—those, namely, in the Saxonian and Polandian stages. Between the moraines and the shores of the Baltic, however, not only two, but three, or even, in some places, four bowlder-clays are known to occur. As we might have expected, however, the occurrence of two or of one only is most usual. German geologists have classified the drift deposits of the Baltic coast-lands in the same way as those of the Elbe valley—recognizing, as in that region, a lower and an upper Diluvium. In short, they consider the upper bowlder-clay of the Baltic coast-lands to be continuous with the upper bowlder-clay that stretches south from the great moraines of the Baltic ridge into the valley of the Elbe. In this view the lower bowlder-clay of the Baltic coast-lands is on the same horizon as the bowlder-clay of the Saxonian stage. On comparing the bowlder-clays of the Baltic lands with those that lie outside of the great terminal moraines it seems to me that this correlation cannot be sustained. The lower bowlder-clay of Holland, for example, has been laid down by a *mer de glace* which flowed in a general southerly direction. But this does not hold true of the so-called lower bowlder-clay of Denmark and Schleswig-Holstein. On the contrary, the two bowlder-clays which occur together in the Baltic coast-lands of that region have both been laid down by ice streaming from east to west out of the Baltic basin. The lower of these bowlder-clays extends across the Cimbric peninsula to the North Sea, while the upper is margined by the great terminal moraines.

The former cannot be correlated with the lower bowlder-clay of Holland, etc., but must occupy the horizon of the Polandian. And this conclusion is further sustained by the fact that the so-called lower bowlder-clay of central Holstein is underlaid by an older groundmoraine, from which it is separated by abundant fossiliferous deposits belonging to the Helvetian stage. In short, the lower bowlder-clay of the Baltic coast-lands is on the horizon of the Polandian stage, while the upper bowlder-clay of the same regions is the groundmoraine of the great Baltic glacier, whose utmost limits are marked by the terminal moraines of the Baltic Ridge.

So far, then, the evidence derived from the Continent points in the same direction as that supplied by the equivalent deposits in Britain. But it carries us further, for in the Baltic coast-lines the youngest bowlder-clay (Mecklenburgian) is separated from the underlying bowlder-clay (Polandian) by an abundant series of fresh-water and marine deposits—some of which indicate cold conditions, while others imply a climate not less temperate than the present. Here, then, is the link in the chain of evidence which we miss in Scotland. If a more or less prolonged temperate interval (Neudeckian) separated the Polandian and Mecklenburgian epochs on the Continent, the same must have been the case in Britain.

Having arrived at the conclusion that a distinct glacial epoch is represented in northern and northwestern Europe by the great Baltic glacier and the district ice-sheets and valley-glaciers of Britain, we might well expect to meet with evidence of a contemporaneous advance of the Alpine glaciers. The three-fold grouping of terminal moraines and associated fluvio-glacial gravels in the Alpine "Vorland" represents, as we have seen, three successive glacial epochs—the Scanian, the Saxonian and the Polandian. Entering the mountains by the main valleys, no conspicuous terminal moraines are encountered for a long distance. Eventually, however, these make their appearance. They are of very considerable dimensions and indicate a time when all the great longitudinal valleys contained large trunk glaciers—none of which, however, reached within many miles the limits attained by the glaciers of the preceding third glacial epoch. The moraines now referred to constitute Professor Penck's "first post-glacial stage," when the snow-line would seem to have been 3000 feet lower than now. So far as I am aware, there is no evidence of interglacial conditions having supervened before the advent of these early "post-glacial glaciers." The moraines in question might simply indicate a pause in the retreat of the great glaciers of the third glacial epoch. It is inconceivable, however, that the very considerable climatic changes which are evidenced by the Neudeckian and Mecklenburgian stages of northern Europe should not have affected the Alpine Lands. And it is, at all events, probable that the moraines of the "first post-glacial stage" are the equivalents of the great moraines of the Baltic Ridge, and the products, therefore, of a separate and distinct glacial epoch. The absence of any Alpine representatives of the Neudeckian interglacial stage need not surprise us—for, as I shall show presently, the occurrence of such deposits in mountain-valleys must always be exceptional.

The stage which I have termed Lower Forestian is one of the most clearly marked in the whole Pleistocene series. In Britain and Scandinavia its position with reference to underlying and overlying accumulations is precisely similar. An Arctic flora occupied the low grounds of both countries during the decay and disappearance of the great Baltic glacier and its British equivalents. To that eventually succeeded a vast forest-growth the relics of which underlie our oldest peat-bogs. The lower forest-bed rests, in short, upon the glacial, fluvio-glacial and marine deposits of the Mecklenburgian stage. At the climax of the Lower Forestian a wide land-surface obtained in northwestern Europe, and the Baltic became a fresh-water lake. Eventually, submergence ensued before those genial conditions had passed away—the marine fauna evidencing warmer waters than now lave the coasts of northwestern Europe.

The next stage (Lower Turbarian) is represented typically in Scotland by the peat which overlies the lower forest-bed and by the raised beaches underneath which the Lower Forestian passes out seawards. The same succession occurs in Scandinavia. Thirty years have elapsed since I first pointed out the significance of this old buried forest and its overlying mantle of peat, and the conclusions I then arrived at have since been supported by the independent researches of Professor Blytt and other botanists and geologists abroad. In subsequent years I had succeeded in gathering much additional evidence. I found that the raised beaches and estuarine deposits which overlie the lower buried forest in our maritime districts, when they are followed inland, eventually pass into fluvio-glacial gravels, and I adduced further evidence to show that during the formation of these beaches and the lower peat of the inland tracts small valley-glaciers existed in the Scottish Highlands. The researches of the Geological Survey have since then shown that these glaciers came down to the sea here and there in the west Highlands and dropped their moraines upon the deposits of the fifty-foot beach. These glaciers I described in *Prehistoric Europe* as "post-glacial glaciers"—meaning by that, glaciers which had come into existence after the disappearance of the minor *mer de glace*. The character of the flora of the lower forest-bed and the wide horizontal and vertical range of the trees, and the facies of the fauna of the *Littorina*-beds of the same stage alike indicate more genial conditions than now obtain in northwest Europe. During the climate of Lower Forestian times it is not at all probable that permanent snow-fields of any kind could have existed in Britain. The glaciers of the succeeding Lower Turbarian epoch were not the attenuated descendants of the great valley-glaciers and district ice-sheets but entirely independent of and unrelated to these.

In southern Norway the great moraines of the Mecklenburgian stage skirt the coast-line. Considerably further inland we encounter another series of large terminal moraines, constituting Dr. Hansen's "epiglacial stage." These moraines I take to be on the same horizon as those of the Lower Turbarian in Scotland. They indicate a snow-line in southern Norway at about 2400 feet, and this corresponds fairly well with the snow-line in Scotland which, during Lower Turbarian times, averaged a height of 2500 feet.

In the Alpine Lands, after leaving the moraines of the "first post-glacial stage," we meet with no more accumulations of the kind until we penetrate far into the lateral valleys, and there another series of conspicuous moraines occurs, forming Penck's "second post-glacial stage." These indicate a depression of the snow-line of about 1600 feet.

The cold, humid conditions of the Lower Turbarian stage were followed by a more genial and drier climate, the evidence of which is abundantly supplied by the upper forest-bed in the peat-bogs of northwest Europe. As this forest-bed with its overlying peat passes out to sea underneath the youngest raised beaches of Britain and the opposite coasts of the Continent, we infer that in Upper Forestian times the land was of wider extent than now. In the Upper Turbarian we in like manner read the evidence of a subsequent relapse to wet and ungenial conditions—the overlying raised beaches indicating further that these conditions were accompanied or followed by partial submergence. To this stage I assign the relatively small moraines which are restricted to the highest mountain-groups in Scotland—the position of these indicating a snow-line at about 3500 feet. Here, however, the evidence lacks the precision of that supplied by the Lower Turbarian. During that stage moraines were deposited upon the fifty-foot beach which overlies the Lower Forestian. But none of the latest high-level moraines approaches the coast-line — we meet with no moraines resting upon the twenty-five-foot beach.

In the mountain valleys of Norway conspicuous moraines occur at higher levels than those which I have correlated with the Lower Turbarian moraines of Scotland, and some of these are probably contemporaneous with the moraines of the Upper Turbarian in Scotland. In the eastern Alps no moraines corresponding to the highest Scottish series are met with, but in the loftier regions of the western Alps they will probably be found when they are looked for.

It is well worthy of note that the glaciers of the Lower and Upper Turbarian stages endured long enough to allow of the erosion of many small valley and corrie-basins. Each glacial epoch indeed was marked by the formation of lake-basins — some excavated in solid rock, others dammed by morainic accumulations. In Scotland the larger valley-lakes date their origin to the epoch of district ice-sheets, etc. (Mecklenburgian stage); a second series of relatively small valley-basins, and innumerable corrie-basins came into existence during the Lower Turbarian stage, while a third set of corrie-basins and a few high-level valley-basins are the beds of the vanished glaciers of Upper Turbarian times.

In every region which has been subjected to glacial action two areas are recognizable — namely a central area of erosion and a peripheral area of accumulation. In the former bare rock predominates and only patchy, interrupted deposits of morainic origin occur — in the latter the products of glacial erosion are accumulated, and the solid rocks are largely concealed. Hence it is in the latter areas that interglacial deposits are most likely to have been preserved. It is further obvious that if one and the same region has experienced a succession of glacial and interglacial conditions, it is rather the accumulations of the later than those of the earlier epochs that will present themselves. The distribution of the interglacial and glacial deposits of Europe shows this clearly enough. Not a trace of the Scanian bowlder-clay has been recognized in Britain, but it is probably represented by the lowest-lying bowlder-clay of the south Baltic coast-lands. Again but for the Norfolkian beds we should never have known that a genial interglacial epoch followed after the passing of the Scanian stage. The area of glacial erosion was so enormously extended during Saxonian times that preëxisting superficial beds in northern and northwestern Europe were almost completely obliterated. Under the Polandian ice-sheet great erosion likewise took place, but the area affected was not quite so extensive. Hardly a trace of the Scottish lower bowlder-clay (Saxonian) occurs in the mountain regions, it is only in the low grounds that it puts in an appearance—becoming more and more conspicuous as the peripheral areas occupied by the minor *mer de glace* (Polandian) are approached. The same tale is told by the corresponding deposits on the Continent. In a word it is in the peripheral areas of glacial accumulation that the deposits of the immediately preceding interglacial epoch are most abundantly preserved. If this be true of the Helvetian and Polandian, it is true also of the Neudeckian and Mecklenburgian stages. The Neudeckian beds are met with chiefly in the southern coast-lands of the Baltic. So again we cannot expect to meet with plentiful relics of the Lower Forestian stage in the mountain valleys which were subsequently occupied by the local glaciers of the Lower Turbarian. It is only in places where these glaciers descended to the low grounds or entered the sea that they were likely to override interglacial deposits and to cover these with their moraines. And this, as we have seen, is just what happened in Scotland—the fifty-foot raised beach clearly underlies the terminal moraines of Lower Turbarian times.

Similar phenomena confront us in the Alpine Lands. It is in the "Vorländer" and the lower reaches of the great mountain valleys that the successive glacial and interglacial stages are best represented. Exceptionally, as in the case of the Hötting beds at Innsbruck, interglacial beds have been preserved under the moraine of the great ice-flow of maximum glaciation. But the beds in question had become indurated by infiltration and converted into solid rock before the advent of that great glacier, and consequently were better able to resist erosion.

It is obvious that the accumulations of glacial and interglacial times which occur over so wide a region in northern and northwestern Europe, and are so well represented in the mountain lands further south, must have their representatives in what we may term extra-glacial tracts. I have spoken of the Norfolkian beds of East Anglia as being the only representatives of that stage that we can certainly recognize in northern Europe. But it seems to me most probable that the fossiliferous deposits which underlie the lower bowlder-clay (Saxonian) of middle Germany occupy the Norfolkian horizon. Be that as it may, we cannot doubt that each interglacial stage must have its equivalent amongst the Pleistocene accumulations of non-glaciated regions. This can be demonstrated in the case of the Lower Forestian stage. It has long been known that a great forest-growth characterized northwestern Europe in what is usually termed the "post-glacial epoch," and that partial submergence of the land subsequently ensued. Now the deposits of this so-called "post-glacial stage" are overlaid in Scotland by a series of moraines—the position of which indicates that the snow-line stood at an average elevation of 2500 feet. The flora and fauna of the Lower Forestian, on the other hand, denote a climate even more genial than the present. Hence the Lower Forestian, capped as it is by glacial accumulations, obviously occupies an interglacial position. In a word, the lower peat-bed occurring under the peat-bogs of northwest Europe outside of the regions reached by the glaciers of the Lower Turbarian stage, is the product of an interglacial epoch, to which succeeded an epoch of manifestly colder conditions. On the same principle and for similar reasons I would assign to interglacial horizons all the Pleistocene alluvial and cave deposits of extra-glacial tracts which have yielded relics of interglacial floras and faunas; while those containing the remains of northern and Arctic forms I look upon as representatives of the several glacial stages.

Thus I would range under the head of Norfolkian not only the "Norwich Forest-bed series" and the equivalent interglacial beds of the Alpine Lands, but the so-called "pre-glacial beds" underlying the Saxonian diluvial formation of middle Germany, etc., together with the *Elephas-meridionalis* beds of France, Italy, etc. The subsequent glacial and interglacial stages must each have representatives in extra-glacial tracts, and I am sanguine enough to believe that the detailed correlation of the former with the latter will some day be accomplished. Already, indeed, progress has been made in this direction. Distinct stages in the Pleistocene alluvia have been recognized not only by means of their organic remains, but by working out their relation to the fluvio-glacial terraces that extend outwards from glaciated regions. In this way it has been proved that no small proportion of the ossiferous and palæolithic river-gravels are on the horizon of the Helvetian interglacial stage. So again with regard to the Löss, recent researches have shown that the areas occupied by this deposit have been tenanted successively by tundra, steppe, and forest-faunas. And, further, as Penck and others have demonstrated, the Löss is not the accumulation of one single epoch, but must be relegated to different stages of the Glacial Period.

Apart altogether from the stratigraphical relations of the Pleistocene alluvia and cave-accumulations to the fluvio-glacial and glacial deposits, it has long been recognized that the organic remains of the former are indicative of climatic oscillations. Did no glacial and interglacial beds exist, we should yet infer from a study of the Pleistocene alluvia and cave-accumulations that great changes of climate must have taken place during their formation. It is clear, in a word, that the Pleistocene deposits of extra-glacial and glaciated regions are merely portions of one and the same geological series—they are of contemporaneous origin. Thus, when the former are followed towards regions of glacial accumulation they eventually disappear under bowlder-clay or other diluvial deposits, or else they are found occupying interglacial positions. It was this remarkable distribution that first suggested to me, many years ago, that these ossiferous alluvia could not be of post-glacial age, as was at that time generally supposed.

In raising the number of glacial epochs from two or three to five or six I am aware that I run the risk of exciting prejudice. If it be hard to conceive of a succession of three glacial epochs, it will seem harder still to admit the possibility of double that number having supervened in Pleistocene times. We are so much the slaves of terminology, that had I restricted the term *epoch* to the first three cold stages, and merely described the last three as indicating *episodal* climatic oscillations in post-glacial times, my conclusions would probably have assumed a less disturbing guise. But the evidence was quite antagonistic to such a division. Before I had ascertained that the district ice-sheets, etc., of Britain (Mecklenburgian stage) represented a distinct glacial epoch—so long as I believed them to be merely the attenuated descendants of the minor *mer de glace* (Polandian stage)—it was possible to hold that the Glacial Period closed with the final disappearance of that particular ice-sheet. Thus the deposits of the 100-foot beach were formerly classed by me as "late glacial"—all the overlying accumulations being included in the "post-glacial and recent series." Some thirty years ago I had adduced evidence to show that oscillations of climate had supervened in post-glacial times—a view which was suggested by the occurrence of successive forest-beds in the peat-bogs of northwestern Europe. The researches of subsequent years tended strongly to confirm that view, and in *Prehistoric Europe* (1881) I showed that upon the decay of the great forests which occupy the bottom of the peat-bogs, the land was partially submerged, the climate became colder and more humid, and snow-fields and valley-glaciers reappeared in the Scottish Highlands These I designated "post-glacial glaciers." I had no thought at that time of including this recrudescence of glaciation as a phase of the Glacial Period proper. I then considered the closing stage of the Ice Age to be represented by the groundmoraine of the minor *mer de glace* and by the moraines of retreat dropped by the great valley-glaciers into which that ice-sheet, as I believed, was finally resolved. The contrast between the *mer de glace* of our upper bowlder-clay, and the terminal moraines of "post-glacial" times was so great that it would have been absurd to include the latter in the Glacial Period proper. The subsequent discovery by Penck of "post-glacial" moraines in the Pyrenees, and the recognition of similar "post-glacial" stages in the Alpine Lands, tended to confirm me in the view that the Glacial Period closed with the disappearance of the vast ice-sheet underneath which our upper bowlder-clay was accumulated. But after I had learned that the district ice-sheets of Britain and the last great Baltic glacier belonged to an independent epoch, separated from the preceding cold epoch by well-marked interglacial conditions of long duration, it became necessary to reconsider the question of classification. The intercalation of the Neudeckian and Mecklenburgian stages at once broke down the climatic barrier, if I may so speak, that seemed at one time to separate glacial from "post-glacial" times. The great contrast between the two no longer exists. What I find is a succession of glacial and interglacial stages, beginning with the Scanian and terminating with the Upper Turbarian. The climax of glacial extension was reached in Saxonian times, after which each cold stage diminished continuously in importance. In like manner the earliest interglacial epoch appears to have been the most genial, each successive epoch approximating more and more closely to existing conditions. In a word, the climates of the later glacial and interglacial phases were less contrasted than those of the earlier stages of the series.

But it may be urged that the earlier climatic stages being so much more pronounced than those of later times, they alone should be considered of epochal importance. Well, much depends upon what we imply by the term epoch. For myself I use it simply as a vague term signifying a relatively long lapse of time. I do not think we have quite unequivocal evidence to show that any one of these epochs was longer or shorter than another. For aught that we can tell all may have been of equal duration. One is apt to infer that the enormous erosion and accumulation evidenced by the Saxonian implies a much longer time than the corresponding work accomplished, say, in the Lower Turbarian epoch. But we may quite well be mistaken in our inference. A horse will do much more work in an hour than a man can accomplish in the same time. So the vast ice-sheets and glaciers of the Saxonian stage, in the work they were able to perform, must necessarily have surpassed the comparatively insignificant ice-flows of a later date. But it is obvious that the erosion of a rock-basin 600 feet deep and twenty-five miles long need not have occupied more time than was required for the excavation of a basin hardly a mile in length and only a few yards in depth. Again, the Saxonian and Polandian bowlder-clays and fluvio-glacial gravels far surpass in importance those of the Mecklenburgian stage, but he would be a rash geologist who should maintain that the thicker and more extensive accumulations necessarily took the longest time for their formation. I am not aware of any evidence that would compel me to infer that the small local glaciers of the Lower Turbarian did not exist for as long a space of time as their gigantic predecessors of earlier glacial epochs. Once more, if we take into consideration the many complex climatic and geographical changes and the several migrations of flora and fauna which characterized the later phases of the Glacial Period, we shall hesitate before concluding that the Mecklenburgian and succeeding stages are less entitled to be classed as epochs than the more strongly contrasted stages that preceded them. And similar remarks apply to the interglacial stages. I do not know how we are to estimate the relative duration of each particular genial epoch. It can be shown that great valley-erosion took place during the earlier interglacial stages; and the persistence of these epochs is still further indicated by the depths to which surface-weathering penetrated. If the epigene agents of change worked no more actively then than they did in later interglacial times or than they do in our own day, we should be led to infer that the earlier were of much longer duration than the later stages. But I doubt whether that inference would be justifiable. Such evidence as we have seems to indicate that the climates of the earlier interglacial stages were warmer and more humid than those of later epochs—and this means more active weathering and more energetic fluviatile erosion. If we base our estimate of the duration of the earlier interglacial epochs upon the present rate of erosion and accumulation, then doubtless we shall be led to conclude that these earlier stages were more protracted than the later. But it would seem more reasonable to take the latest interglacial epochs—those, namely, which approached most nearly to existing conditions—and endeavor to measure the duration of these by reference to the present rate of erosion. If we could ascertain approximately the time required for the erosion and accumulation which took place during the Lower or the Upper Forestian stage we should perhaps have a better index to the duration of interglacial epochs generally. In a word, the present rate of epigene action cannot be much less than that of late interglacial times, but it must have been considerably exceeded by that of earlier interglacial stages.

For ready reference I append a tabular statement of the glacial succession in Europe:

EUROPEAN GLACIAL AND INTERGLACIAL STAGES.

XI. Upper Turbarian = Sixth Glacial Period.
X. Upper Forestian = Fifth Interglacial Period.
IX. Lower Turbarian = Fifth Glacial Epoch.
VIII. Lower Forestian = Fourth Interglacial Epoch.
VII. Mecklenburgian = Fourth Glacial Epoch.
VI. Neudeckian = Third Interglacial Epoch.
V. Polandian = Third Glacial Epoch.
IV. Helvetian = Second Interglacial Epoch.
III. Saxonian = Second Glacial Epoch.
II. Norfolkian = First Interglacial Epoch.
I. Scanian = First Glacial Epoch.

James Geikie.